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KRAFT PULPING CHARACTERISTICS OF HICKORY WOOD/BARK MIXTURES

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ABSTRACT

Hickory wood/bark chip mixtures were prepared that ranged from 0 to 40% bark. The mixtures were pulped using a kraft procedure and the resulting pulps refined and handsheets evaluated. Pulp yields decreased as bark levels increased, with bark yields running at about 1/4 that of the wood. Pulp freeness was generally lower and burst, breaking length, MIT fold and tensile energy absorption increased with increasing bark levels. Tear was greatest at bark levels of 15% and was only 8-16% lower than the "wood only" pulps when bark levels were increased to 40%.

Introduction

Hickory species (*Carya*) are found growing on a wide variety of sites in the eastern United States. The hickories are a ring porous hardwood and, although they possess adequate fiber length and strong, dense wood, there has been a lack of adequate markets for hickory. As a result, when oak-hickory stands are cut, the hickory is often left behind, thus increasing the amount found in poorly managed, mixed hardwood stands.

Hickory has not been widely used by the paper industry, despite early work by Keller (1,2) which demonstrated that hickory chips containing 19% bark, when cooked by the neutral sulfite procedure, could be utilized not only for linerboard and corrugating medium but in better grades of paper.

Hickory is difficult to debark and it appears the lack of knowledge about the bark of the pulpwood species, combined with prejudice against the use of bark regardless of its characteristics, has hampered the utilization of hickory by the paper industry. Studies at The Institute of Paper Chemistry (3) demonstrated the dormant season debarking difficulties encountered in a number of hardwood species were associated with the presence of fiberlike phloem elements in the inner bark. These observations prompted the kraft pulping of the hickory wood/bark mixtures described below.

Methods and materials

Three shagbark hickory trees (Carya ovata), ranging from 8.8 to 10.4 inches in diameter and 58 to 62 feet in total height at ages 95 to 115 years, were cut and sampled for variation in bark characteristics.* The percent bark for the main stem up to a 4-inch top (volume basis) was estimated to range from 11.4 to 12.8%. Three six-foot bolts were collected from the smallest tree (8.8 inches dbh, 62 feet height, 95 years) at the 6-12, 17-23, and 36-42-foot heights and used in estimating the pulping characteristics.

The three six-foot bolts were chipped in a Carthage chipper, air dried, screened and the chips passing the 32 x 25 mm screen and retained on the 6 x 6 mm screen were used for pulping. Following screening, all bark was removed from the samples and the bark was then recombined on a weight basis to give the following mixtures: 100% wood, 85% wood/15% bark, 74% wood/26% bark, 60% wood/40% bark and 100% bark.

*Bark variation study by Vizvary (5).

All cooks were carried out in an IPC microdigester using the methods described by Thode, et al. (4) with the simulated kraft cooking conditions described in Table I. Each cook yielded about 45 grams o.d. pulp and, to obtain suitable amounts for refining, the number of cooks listed in Table III were made on each chip mixture. Pulps from cooks utilizing the same chip mixture were combined and refined in a PFI mill at a 10% consistency. Handsheets were made according to the TAPPI Standard Method T 205 and conditioned at 50% relative humidity and 72°F prior to testing. TAPPI Standard Method T 220 os-71 was employed and the strength properties tested included breaking length, stretch, tensile energy absorption (TEA), burst factor, tear factor, and MIT fold. Light scattering coefficient was also measured to provide an estimate of inner fiber bonding.

[Table I here]

The fiber measurements were based upon 300 fibers for fiber length and 100 fibers for fiber width and cell-wall thickness. Projected fibers and the IPC semiautomatic fiber measuring instrument were used for fiber length. A light microscope with a 400X objective was used for fiber width and cell-wall thickness measurements.

Wood and bark properties

Wood and bark properties were measured using both pulp and chip samples. The results of these measurements are summarized in Table II. The specific gravity of the bark was greater than the wood and, as illustrated in Fig. 1, contained bands of phloem fibers in the inner bark. Measurements made on intact fibers from the inner and outer bark and at varying heights in the tree revealed that there was very little difference in bark fiber length due to location. The fiber length of unbroken phloem fibers averaged 1.06 mm with an estimated maximum variation due to position within the tree of ± 0.02 mm (5).

[Table II and Fig. 1 here]

The bark (phloem) fibers of hickory are characterized by a gelatinous layer similar to that of tension wood. Meaningful measurements of cell wall thickness were difficult on collapsed bark fibers and, as a result, all cell wall thickness measurements were confined to the true cell wall, excluding the thickness of the gelatinous layer. The gelatinous cell wall layer was estimated to be approximately twice as thick as the normal cell walls, making the total effective cell wall thickness 7 to 10 μm. Briefly, the bark fibers are slightly shorter in length, greater in width and have thicker cell walls, if the gelatinous layer is included, than comparable wood fibers.

Pulp yield

Cooking conditions were held constant and the resulting pulp yield and kappa numbers recorded. Table III summarizes the information obtained. Under the established cooking conditions, the lignin-free yield of the wood was 49.5% while that of the bark was 26.2%. The reason for bark yield being about half that of the wood is because of the high levels of thin-walled parenchyma and sieve cells that break down and are lost during screening when cooking conditions are relatively severe.

[Table III here]

Reactions to refining

Refining was investigated by beating the pulps in a PFI mill at 10% consistency and measuring the Canadian Standard freeness and pulp strength after a specific number of revolutions of the PFI mill*. Table IV summarizes the refining levels used and the freeness information obtained.

*One count equivalent to 10 revolutions of the PFI mill.

Increasing the level of bark decreased the pulp freeness, but the pulps with up to 40% bark did not react much differently to refining than the "bark-free" pulps. Freeness levels after 400 counts were very similar and ranged from 315 to 349. Pulps of 100% bark had very low freenesses and, when beaten at the 150 to 400 count level, could not be formed into suitable handsheets for testing. Reaction to refining and strength properties are presented for the 100% bark handsheets at the zero and 50 count refining levels only.

[Table IV here]

Handsheet strength properties

Handsheet strength properties and light scattering coefficient data are summarized in Table IV. Analyses of variance (ANOV) and Duncan's Multiple Range Test were run on the strength properties of tear, burst, breaking length, MIT fold, stretch, tensile energy absorption, and light scattering coefficient, using 150 and 400 count refining level data. These comparisons are summarized in Table V. In addition, Fig. 2 and 3 illustrate the influence of bark levels on tear and breaking length.

[Table V and Fig. 2 & 3 here]

Discussion of results

Use of pulpwood species without debarking appears to be a viable alternative where debarking is difficult, the bark contains usable amounts of fiber and the utilization of the bark does not increase pulping costs or greatly decrease yield or strength properties. Kraft pulping results with shagbark hickory indicate chip mixtures containing up to 40% bark could be satisfactorily pulped and produce pulps with adequate strength properties.

Fiber measurements on pulp samples indicate that average fiber length decreased as the percent bark increased. The average fiber length for pulp from 100% bark was 0.84 mm while that from 100% wood was 0.95 mm. Unbroken, carefully isolated bark fibers averaged 1.06 mm (5) and varied little with position within the tree. Literature fiber length values for hickory wood are reported to be 1.3 mm (3).

Hickory, because of its high specific gravity, can be expected to produce a high pulp yield per cord. Pulp yield in this study decreased as the percent bark increased. Yield for the 100% wood sample, after correction for lignin in the pulp, was 49.5%. Based upon the yield loss resulting when 15, 26 and 40% bark was pulped, it appears the resulting fiber yield for hickory bark is only 11-15%, considerably less than the 26.2% yield reported when 100% bark was pulped. The low freeness and difficulties encountered in washing and screening the 100% bark pulps are believed to be the reason for the higher yield reported for 100% bark.

Sheet drainage and response to refining is of concern when bark pulps are utilized. Response of the several sources of pulp to refining was not greatly different. The presence of bark fibers and nonfibrous elements decreased pulp freeness, although not as much as anticipated. Changes in freeness as the result of refining were about the same regardless of the amount of bark present. Freeness for the four types of pulps varied from 315 to 349 at the highest level of refining.

Pulp strengths are of particular interest to the papermaker and turned out to be better than anticipated. The pulp properties of shagbark hickory were comparable to the values reported for southern hardwood pulps (6) and had greater tear, similar bursts and lower tensile strength than aspen kraft pulps (7). The presence of bark fibers resulted in significant increases in tear, burst, breaking length, and MIT fold. Stretch appeared to be little influenced by varying bark levels from 0 to 40%. TEA was little influenced by the presence of bark fibers except when 40% bark was used. TEA was significantly higher for the 60% wood/40% pulps. MIT fold exhibited the greatest improvement as the result of the presence of bark fibers in the furnish with fold endurance being the greatest when the bark level in the original chip mixture was 40%.

Statistical significance of the differences reported in strength properties was checked by comparing the strength values at two refining levels, 150 and 400 (Table V). These calculations confirm that significant improvement in strength properties resulted from the inclusion of bark fibers in the handsheets tested. The Duncan's Multiple Range Test indicated those means that were significantly different. Tear factor and MIT fold were the properties most influenced by the presence of bark fibers. Figure 2 illustrates that the inclusion of 15% bark improves the tearing strength; however, at the higher levels of bark, tear is less than for the 100% wood fiber handsheets. The poorer tear at the higher bark levels is very likely the result of increasing numbers of parenchyma-type cells and a decreasing average fiber length of the resulting pulps.

Plotting tear values *vs.* tensile strength at several beating intervals is a useful method of ranking pulps as to their relative value as a papermaking material. Tensile strength (breaking length) is a paper property very often included in manufacturing specifications and pulp furnishes require refining to reach the required levels. Refining tends to reduce tearing strength so that a pulp that retains tearing strength at a given level of tensile strength development can be considered to be superior. Figure 3 illustrates this approach and again demonstrates the improved strength properties of the pulps containing modest levels of thick-walled bark fibers and greater numbers of parenchyma cells.

These results confirm earlier studies (1,2) investigating the usefulness of hickory for chemical pulps. Tension woodlike bark fibers occur in large numbers in both the inner and outer bark of shagbark hickory. The mechanisms involved are not clear, but the results indicate that modest levels of bark fibers improve rather than reduce pulp strength properties of hickory pulps. Additional detailed evaluations are underway on the fiber properties important in predicting paper properties of hardwood pulps.

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I. Microdigester cooking conditions

Maximum temperature, °C	170
Time to maximum temperature, min	65
Time at maximum temperature, min	60
Sulfidity, %	20
Active alkaline, %	20
Concentration of chemicals, as Na_2O, g/L	49
Liquor to wood ratio	4:1

II. Specific gravity and wood and bark fiber dimensions[a]

Fraction	Specific gravity	Fiber length, mm	Fiber width, μm	Cell wall thickness, μm
Bark	0.78	0.84	20.2	2.50[b]
Wood	0.67	0.95	13.6	4.55

[a]Fiber dimensions measured on lightly beaten pulp sample. [b]Cell wall thickness excludes thickness of gelatinous layer.

III. Pulp yield and kappa number

Chip fraction	No. microcooks	Yield, %	Kappa no.	Correct yield, %[a]
100% Wood	4	51.8	15.4	49.5
85% Wood/15% bark	4	47.0	21.1	43.9
74% Wood/26% bark	5	43.0	23.9	39.5
60% Wood/40% bark	7	39.8	27.3	35.8
100% Bark	6	32.7	44.1	26.2

[a]Yield corrected to a lignin-free basis; obtained by using kappa no. to estimate lignin remaining in the pulp.

IV. Freeness and handsheet strength properties

Handsheet origin	Refining level, counts	CS freeness, mL	Breaking length, km	Stretch, %	TEA, kg m/m^2	Burst factor	Tear factor	MIT fold	Apparent density, g/cc	Light scattering coefficient, cm^2/g
100% Wood/0% bark	0	546	4.56	1.87	3.08	24.3	106	6	0.498	430
	150	541	6.09	2.84	5.69	37.3	129	27	0.572	342
	250	410	7.25	3.69	8.71	51.1	146	103	0.612	326
	400	315	8.25	4.24	11.66	57.9	139	371	0.634	302
85% Wood/15% bark	0	551	4.67	2.10	3.27	24.5	117	6	0.486	384
	150	462	6.31	3.25	7.16	44.5	163	55	0.588	329
	250	405	7.25	3.80	9.07	50.3	164	134	0.603	337
	400	349	7.55	3.73	9.24	55.2	146	303	0.640	329
74% Wood/26% bark	0	506	5.13	2.27	3.85	28.0	120	13	0.514	378
	150	436	6.95	3.24	7.33	45.0	136	69	0.592	331
	250	384	7.32	3.64	8.86	51.6	130	145	0.627	313
	400	323	8.18	4.18	10.80	58.7	131	556	0.639	294
60% Wood/40% bark	0	490	6.54	2.42	6.49	37.5	112	51	0.550	271
	150	415	7.95	3.11	10.18	51.9	118	164	0.593	251
	250	390	7.81	3.17	10.17	50.5	122	181	0.574	259
	400	315	9.03	3.76	14.03	72.1	116	1175	0.666	229
0% Wood/100% bark	0	285	4.74	2.54	4.08	27.5	74	39	0.480	350
	50	260	5.13	3.15	5.46	34.3	75	76	0.506	357

V. Results of ANOV and Duncan's Multiple Range Test (8) for differences caused by bark levels

Handsheet origin	Breaking length, km		Burst factor		Tear factor		MIT fold		TEA, kg m/m^2	
	150	400	150	400	150	400	150	400	150	400
100% Wood/0% bark	6.09^x	8.25^y	37.3^x	57.9^x	129.0^{yz}	138.6^{yz}	26.8^x	371^x	5.69^x	11.64^y
85% Wood/15% bark	6.31^x	7.54^x	44.5^y	55.3^x	162.8^x	146.2^z	55.0^y	293^x	7.16^y	9.24^x
74% Wood/26% bark	6.95^y	8.18^y	45.0^y	58.7^x	136.2^y	131.2^y	69.4^y	556^y	7.33^y	10.79^y
60% Wood/40% bark	7.95^z	9.03^z	51.9^z	72.1^y	118.0^z	116.2^x	165.2^z	1175^z	10.18^z	14.04^z
F-Test for materials	70	23	114	46	20	10	76	49	22	23

[a]Values greater than 5.3 indicate differences between means are significant at the 1% probability level.

[xyz]Means followed by a common superscript are not significantly different.

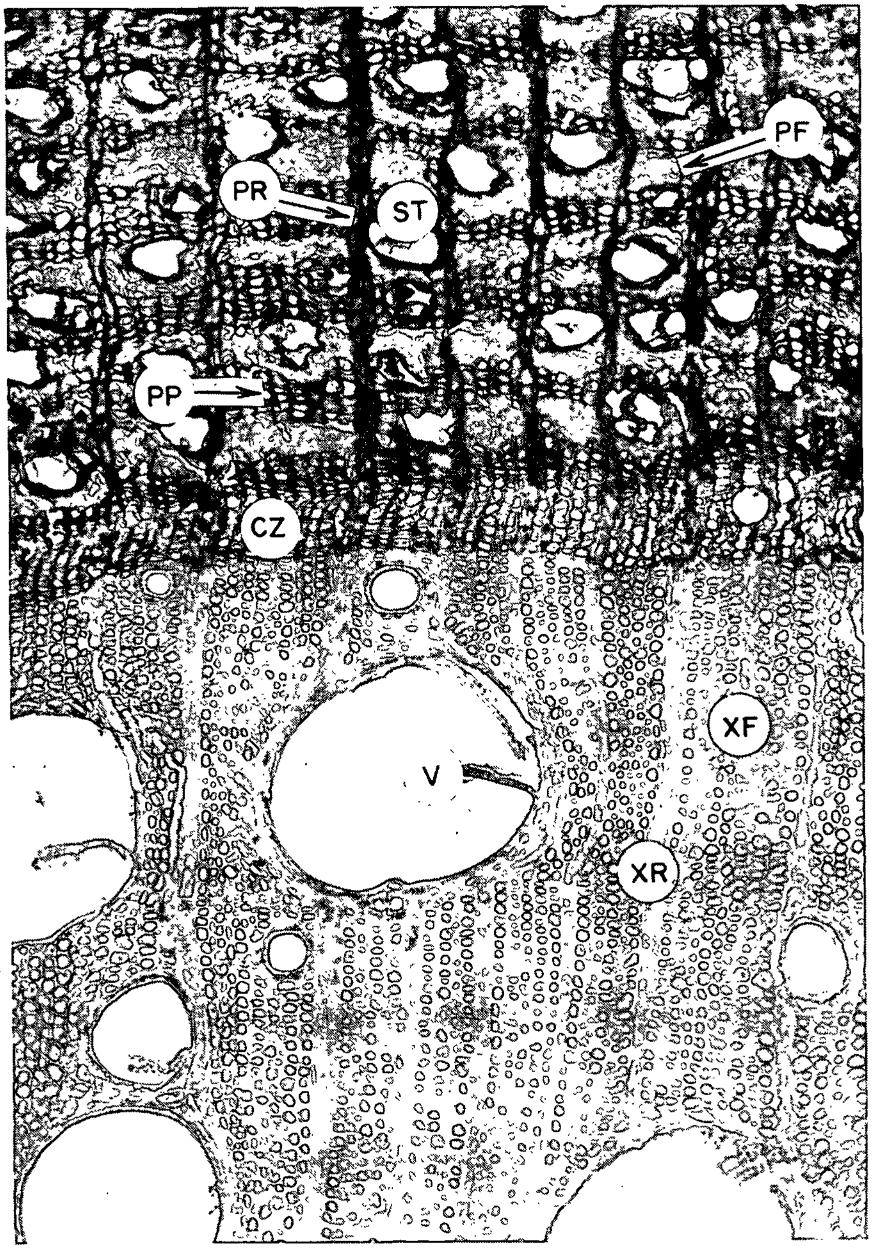

Fig. 1. Illustrated is the xylem and inner bark of shagbark hickory. The symbols indicate xylem fibers (XF), xylem ray (XR), vessel (V), cambium zone (CZ), phloem parenchyma (PP), phloem ray (PR), sieve tubes (ST), and phloem fibers (PF). Magnification — 120X.

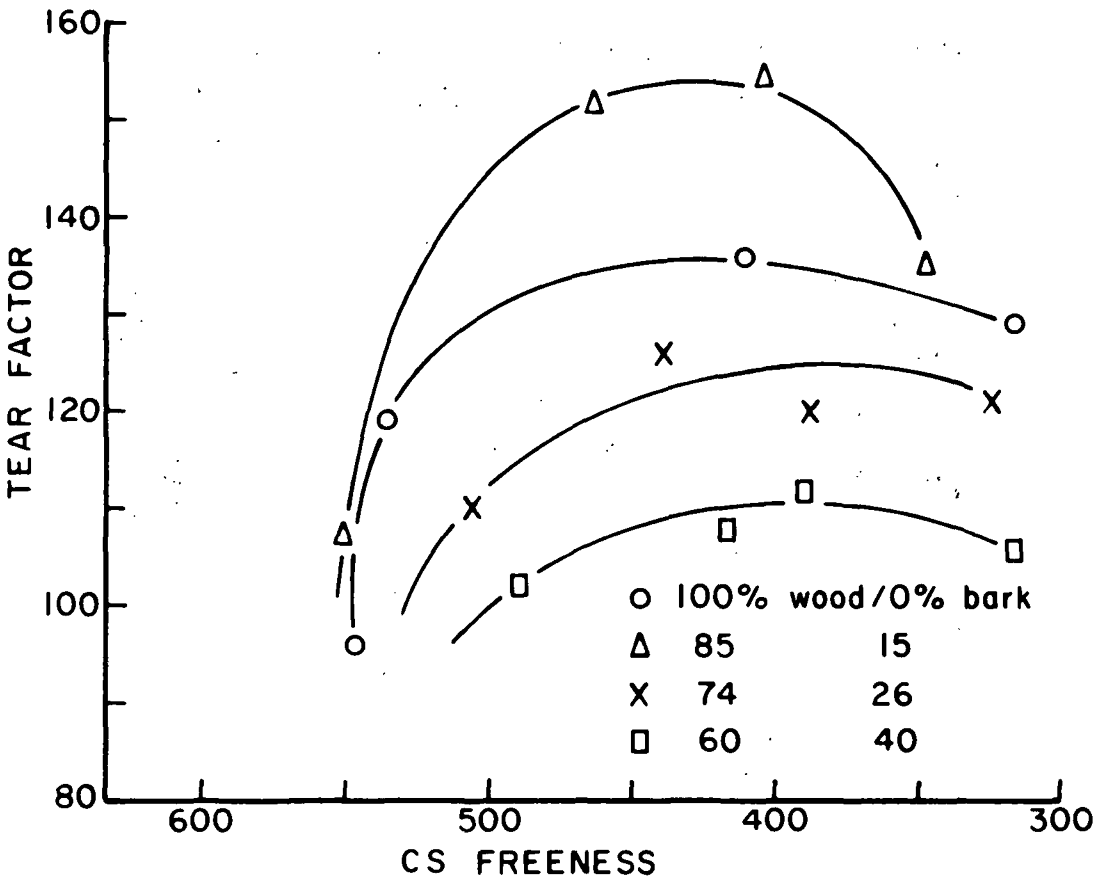

Fig. 2. The curves illustrate the influence of bark % on tear factor.

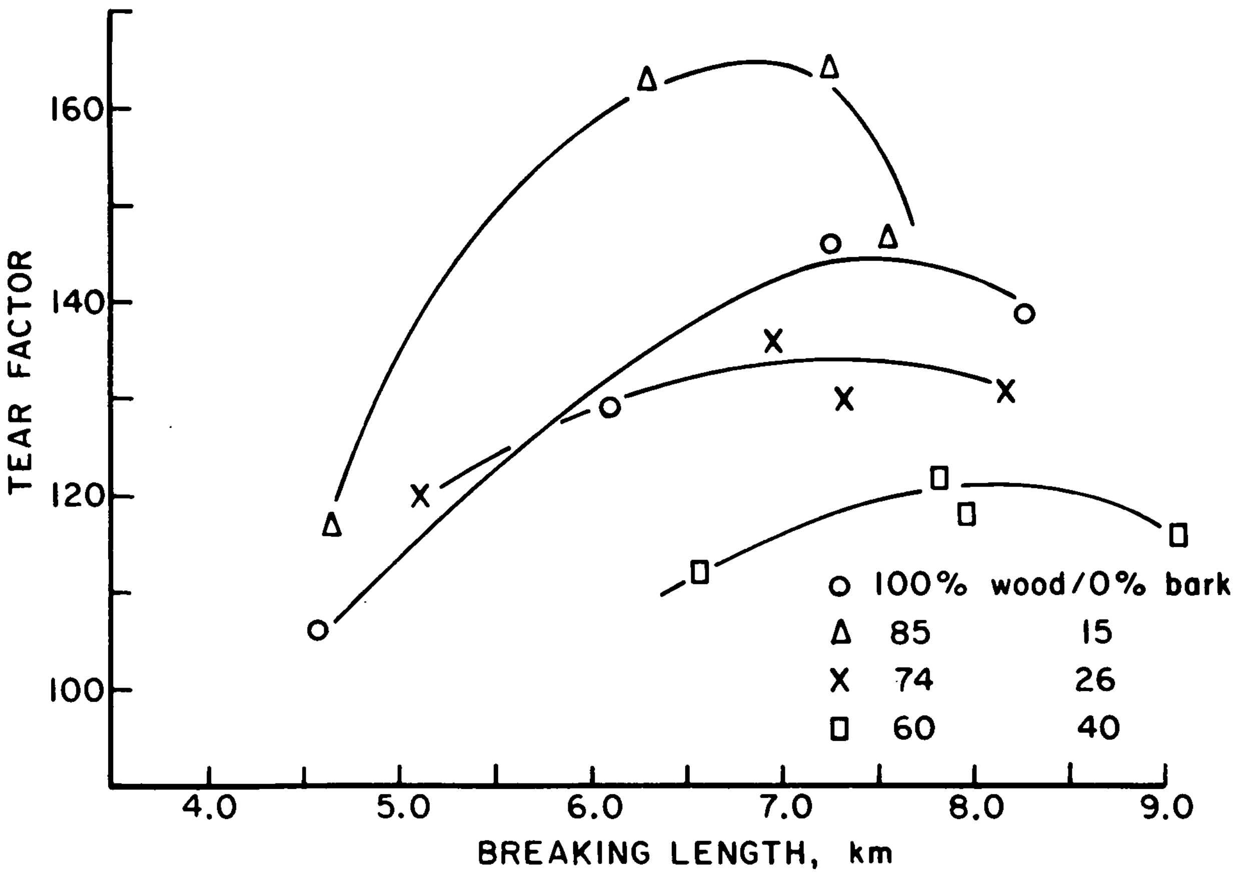

Fig. 3. The curves illustrate the influence of bark levels on tear and breaking length. When bark levels were 15%, moderate beating produced pulp with high tear and acceptable breaking length.